

SUCCESSIVE INDEPENDENCE AND BEHAVIORAL CONTRAST IN A CLOSED ECONOMY

K. GEOFFREY WHITE, BRENT ALSOP, AND ANTHONY P. MCLEAN

UNIVERSITY OF OTAGO AND UNIVERSITY OF CANTERBURY
NEW ZEALAND

Two pigeons had access to multiple concurrent schedules of reinforcement for 24 hours per day in their home cages. The variable-interval schedules comprising the multiple concurrent schedules were varied across 16 conditions. In three sets of conditions, one schedule was varied while its concurrent alternative and the concurrent schedules in the other component were held constant. Behavioral contrast was observed; that is, as the rate of reinforcement arranged by the varied schedule decreased, response rates on the constant schedules typically increased. These conditions formed part of two larger sets of conditions in which the concurrent schedules in one multiple-schedule component remained constant while the concurrent schedules in the other component were varied. Successive independence was found, in that behavior allocation during the constant component did not vary as a function of the reinforcer ratios in the varied component. Successive independence between components in multiple concurrent schedules is a robust result that occurs in closed economies and under conditions that promote behavioral contrast.

Key words: closed economy, successive independence, behavioral contrast, variable-interval schedules, multiple concurrent schedules, key peck, pigeon

Subjects allocate their behavior between two concurrent alternatives in an orderly, quantifiable manner. This relation is a power function known as the generalized matching law. In logarithmic terms, this relation is

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{R_1}{R_2}\right) + \log c, \quad (1)$$

where the subscripts 1 and 2 refer to the two concurrent alternatives, B refers to numbers of responses, and R refers to numbers of reinforcers produced by responding (Baum, 1974b). The parameter a measures the extent to which changes in the ratio of obtained reinforcers (R_1/R_2) produce changes in behavior allocation (B_1/B_2). This a parameter is called sensitivity to the reinforcer ratio and typically takes a value between 0.7 to 0.9 (Taylor & Davison, 1983; Wearden & Burgess, 1982). The parameter c measures any preference or bias for one of the alternatives that remains constant across changes in the reinforcer ratio (Baum, 1974b).

However, behavior also varies as a function

of reinforcer ratios in the context of successively, rather than concurrently, available schedules (e.g., Lander & Irwin, 1968). In a typical multiple schedule, two stimuli alternate for fixed periods of time and each is associated with its own schedule of reinforcement. According to Williams (1988), behavior in one component is "inversely related to the context of reinforcement in which it occurs" (p. 213). Because the reinforcement context in multiple schedules includes the temporally distant component, any mechanism for multiple-schedule performance must account for a problem not present in concurrent schedules; that is, the manner in which a schedule in one component affects performance on another temporally removed component. Contemporary research focusing on this problem has used procedures that combine aspects of both concurrent-schedule and multiple-schedule procedures. This procedure is known as a multiple concurrent schedule (e.g., McLean, 1988, 1991).

A recent study by McLean (1991) provides a useful example for describing multiple concurrent schedules and for presenting some of the major findings in this area. In his experiment, two multiple-schedule components alternated every 100 s. Concurrent schedules were in effect during each component. In Com-

Address correspondence and reprint requests to K. G. White or Brent Alsop, Department of Psychology, University of Otago, Dunedin, New Zealand.

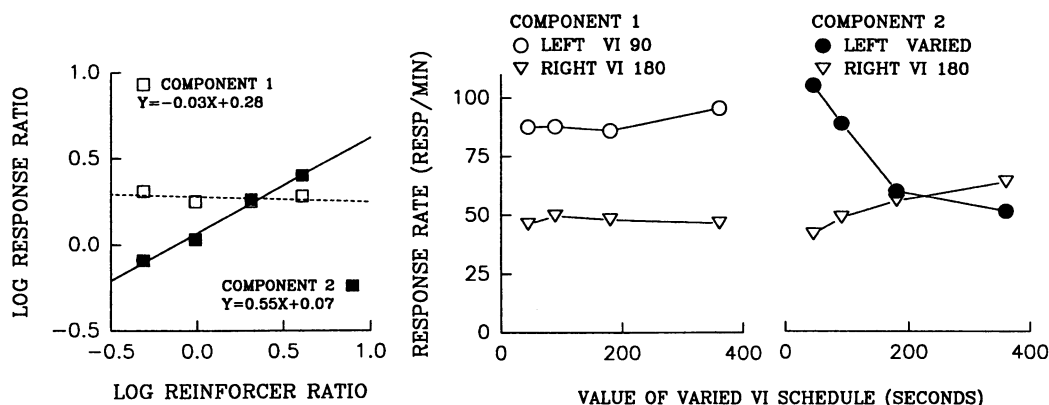


Fig. 1. Group data from McLean (1991). The right panel shows behavior allocation across the concurrent schedules in each multiple-schedule component as a function of obtained reinforcers in the varied Component 2. The remaining panel shows the absolute response rates on each key for each component of the multiple concurrent schedule as a function of the arranged VI schedule on the varied key.

ponent 1, the side keys were lit red, the left-key schedule was always variable interval (VI) 90 s, and the right-key schedule was always VI 180 s. In Component 2, the side keys were lit green and the left-key schedule was always VI 180 s. The right-key schedule was varied across conditions from VI 45 s to VI 360 s.

Figure 1 shows a reanalysis of the group data from the study of McLean (1991). These group data are representative of the individual subjects' performances. In the left panel, the data from each component were analyzed using the generalized matching law (Equation 1). Component 2, which contained the varied VI schedule, showed the typical positive relation between the obtained reinforcer ratio and behavior allocation. However, the response ratio in Component 1 showed no change when plotted as a function of the obtained reinforcer ratio in Component 2. In other words, behavior allocation within Component 1 was unaffected by changes in the distribution of reinforcers (and responses) in Component 2. This effect is known as the *successive independence* of behavior allocation in multiple concurrent schedules (McLean, 1988, 1991; McLean & White, 1983).

The right panels of Figure 1 show the absolute response rates on each key in Components 1 and 2 (McLean, 1991). These results, on one level, simply reiterate the findings of the generalized matching law analysis. As the reinforcer rate on the varied left-key schedule in Component 2 decreased, the response rate on the Component 2 left key decreased and

the response rate on the concurrently available right key increased. There was no change in the relation between the response rates on left and right keys in Component 1. However, the Component 1 absolute response rates also show a result not evident in the generalized matching law analysis; that is, the overall level of responding remained constant across changes in the reinforcement schedules in Component 2. This result is somewhat unusual. In standard multiple schedules, decreasing the rate of reinforcement in one component tends to increase the rate of responding in an unchanged component (Williams, 1983). This phenomenon is known as *behavioral contrast*. So, although the results of McLean's (1991) multiple concurrent schedules showed successive independence, they did not show multiple-schedule behavioral contrast.

This poses an interesting question: When changes in one component of a multiple schedule are shown to influence performance in the other component (i.e., behavioral contrast), does successive independence still occur? Obviously, McLean's (1991) study cannot answer this question (Figure 1). A study by Catania (1961) obtained behavioral contrast in a multiple concurrent schedule, but it was unclear from his group average response rates whether response allocation showed successive independence or successive dependence between components.

McLean (1988) attempted to resolve this matter. Three subjects were trained in two sets of conditions. Each set was similar to those

described above in McLean's (1991) study. The results of this experiment were somewhat mixed. There was some evidence of behavioral contrast. However, the changes in absolute response rates were quite small in two of the six sets of data, and the change was in a direction inconsistent with contrast in another set. More important, it was unclear whether there was successive independence between components. Two of the 3 subjects showed some evidence of a positive relation between behavior allocation in the unchanged component and the reinforcer distribution in the varied component. Overall, McLean's results supported successive independence, but the data were not compelling. Therefore, the issue of the relation between behavioral contrast and successive independence remains largely unresolved.

The present study had two aims. First, it investigated whether successive independence was also a feature of performance between components of multiple concurrent schedules in 24-hr closed-economy procedures. The operant-conditioning interface was mounted in the home cage, the multiple concurrent schedules ran continuously, and all food was obtained by responding on the VI schedules. This is a necessary extension of the research in this area. Other studies have shown that behavior in 24-hr closed-economy procedures can differ markedly from that observed in standard 1-hr open-economy procedures. For example, response differentials between multiple-schedule components are far more extreme in closed economies than in open economies (Elliffe & Davison, 1985). Similarly, La Fiette and Fantino (1988) found that increasing the length of multiple-schedule components had effects in closed economies opposite to those observed in open economies. Therefore, the closed-economy procedure provides a proving ground of the generality of successive independence, and, by extension, its related theoretical contributions (e.g., McLean & White, 1983).

Second, some conditions were arranged that allowed examination of behavioral contrast in multiple concurrent schedules. It was hoped that the closed-economy procedure would promote behavioral contrast between multiple components. This would provide a stronger test of the relation between behavioral contrast and successive independence than has been possible in previous research (e.g., McLean, 1988).

Table 1

The sequence of experimental conditions. The VI schedules arranged on each key in Components 1 and 2, the birds' mean body weights over the last 5 days, and the number of days of training are shown for each condition.

Condition	Component 1		Component 2		Weight		Days
	Left	Right	Left	Right	R4	G1	
1	15	80	80	360	445	400	15
2	80	15	80	360	440	395	15
3	40	200	80	360	440	385	16
4	200	40	80	360	440	385	21
5	15	80	80	360	445	390	15
6	360	15	80	360	440	390	16
7	480	15	80	360	440	390	15
8	80	15	400	360	437	386	15
9	150	800	800	3,600	415	381	15
10	150	400	400	1,800	425	385	15
11	400	150	400	1,800	440	390	14
12	200	1,000	400	1,800	430	380	15
13	1,000	200	400	1,800	430	350	15
14	400	400	400	1,800	430	370	15
15	1,800	400	400	1,800	412	366	15
16	400	1,800	400	1,800	426	370	14

METHOD

Subjects

Two adult homing pigeons, G1 and R4, served as subjects. The birds had about 10 years of prior experience in various standard short-session multiple-schedule procedures before the present experiment. Their ad lib body weights were 401 g and 432 g, respectively. Their mean body weights across the last 5 days of each experimental condition are shown in Table 1. The birds received all their food by working on an operant-conditioning interface in their home cages, and water and grit were freely available. These cages were located one above the other in the pigeon colony room. A tray beneath each cage allowed cleaning every 2 to 3 days without removing the bird. The usual day-to-day activities associated with a pigeon colony took place throughout the experiment. The room was naturally lit and received 12 hr of artificial lighting during the day.

Apparatus

The pigeons were housed in cages (40 cm by 40 cm by 40 cm). Water and grit containers were located midway along one side. A standard operant-conditioning interface (35 cm by

34 cm) was attached to one end of the cage. Mounted on the interface panel were two Gerbrands normally closed response keys, located 10 cm either side of center and 24 cm above the floor. Each key could be illuminated red or green. An effective response required a force of 0.1 N to a lit key and produced a 50-ms offset of the keylight. Reinforcement consisted of 3-s access to a central grain hopper located 5 cm above the floor. During reinforcement, all keys were dark and the hopper was illuminated white. A BBC computer running Spider software, located in another room, controlled all experimental events and recorded the data.

Procedure

The birds were weighed at approximately 10:00 a.m. each morning, after which the daily session began. It took approximately 2 min to remove the bird from its cage and weigh it. Apart from this period, the multiple concurrent schedules were in effect for 24 hr.

Each daily session began with Component 1 of the multiple schedule. The left and right keys were lit green, and responses to each key were reinforced according to independent VI schedules (Fleshler & Hoffman, 1962). After 150 s, Component 1 was suspended and Component 2 began immediately. The side keys were lit red, and a different pair of concurrent VI VI schedules was in effect. Component 2 was suspended after 150 s and Component 1 resumed. The two components alternated in this manner until the end of the session. While a component was suspended, its associated VI schedules stopped timing, but reinforcers not obtained were not canceled.

Table 1 shows the arranged mean intervals of the concurrent VI VI schedules used in Components 1 and 2 of each experimental condition. A 2.5-s changeover delay (COD) was also in effect during the concurrent schedules; that is, a response to a key was reinforced only if 2.5 s had elapsed since the first response on that key following responding to the alternative key.

The number of responses to each of the four VI schedules and the number of corresponding obtained reinforcers were recorded daily for each bird. These data, summed across the last 5 days in each experimental condition, were used in the analyses. Each condition ran for 14 to 16 days, except when external events

(e.g., power failures, equipment breakdown) necessitated continued training (Table 1).

RESULTS

Table 2 shows the data from the last 5 days of each experimental condition for both birds. These results consist of the response rate (responses per hour) and the obtained reinforcer rate (reinforcers per hour) for each of the two VI schedules in each component. Although the data from Conditions 8 and 9 are included to provide a complete record, these results were not used in subsequent analyses.

Behavioral Contrast

Three sets of conditions directly addressed the issue of behavioral contrast in multiple concurrent schedules. The first set consisted of Conditions 2, 6, and 7 (Table 1). Three of the four VI schedules remained constant across these conditions: the right key (VI 15 s) in Component 1 and the left key (VI 80 s) and right key (VI 360 s) in Component 2. The VI schedule on the left key of Component 1 was varied across conditions (VI 80 s, VI 360 s, and VI 480 s).

Figure 2 shows response rates to the two side keys in Components 1 and 2 as a function of the value of the varied VI schedule in Conditions 2, 6, and 7. The pattern of response rates from Component 1 was consistent with that from McLean's (1991) multiple concurrent-schedule study (Figure 1) and with standard concurrent-schedule data (e.g., Alsop & Elliffe, 1988). As the arranged reinforcer rate on the left key decreased (i.e., longer VI schedules), response rates to that key decreased and response rates to the concurrent alternative increased.

Unlike McLean's (1991) findings (Figure 1), however, response rates during the unchanged Component 2 also varied as a function of the Component 1 schedules (Figure 2, Table 2). For both birds, response rates to the left key in Component 2 increased as the arranged reinforcer rate on the left key in Component 1 decreased. The response rates to the right key in Component 2 increased for Bird G1 but decreased for Bird R4.

The second set of conditions (Conditions 10, 14, and 15) was similar in arrangement to the first set. The VI schedules on the right key of Component 1 (VI 400 s) and the left and right

Table 2

The response rates and reinforcer rates on the left- and right-key VI schedules during Components 1 and 2 for both subjects in each experimental condition.

Subject	Condition	Responses per hour				Reinforcers per hour			
		Component 1		Component 2		Component 1		Component 2	
		Left	Right	Left	Right	Left	Right	Left	Right
Bird G1	1	58.3	6.3	4.1	2.6	11.7	0.7	1.6	0.2
	2	13.0	45.3	10.0	4.4	2.5	5.9	2.0	0.5
	3	28.9	0.5	13.5	0.1	8.6	0.1	4.2	0.0
	4	16.9	36.1	33.6	14.1	3.3	3.5	5.8	0.9
	5	72.2	4.6	23.0	5.4	16.2	0.3	4.3	0.4
	6	8.9	63.8	44.3	9.0	1.7	8.1	6.0	1.0
	7	5.7	78.9	33.1	11.8	1.3	9.4	4.2	1.2
	8	13.9	78.0	17.9	11.0	3.0	9.3	1.4	1.2
	9	212.1	77.0	49.8	26.4	9.3	1.5	1.9	0.5
	10	93.3	48.0	39.7	15.7	8.6	2.1	3.5	0.6
	11	49.2	134.3	38.5	20.4	3.6	5.3	3.3	0.6
	12	120.5	61.7	42.8	26.5	6.5	1.2	3.3	0.6
	13	43.1	201.8	101.5	47.2	1.6	5.3	3.4	0.8
	14	118.5	134.7	93.5	49.0	3.7	3.0	3.4	0.8
	15	59.6	228.0	174.8	90.1	1.0	3.3	3.8	0.9
	16	99.3	55.4	87.2	54.0	3.9	0.8	3.6	0.9
Bird R4	1	57.7	2.9	7.9	1.4	9.8	0.2	2.3	0.1
	2	13.4	43.3	11.8	4.8	2.5	6.1	2.5	0.5
	3	52.8	6.0	23.4	3.6	6.8	0.3	4.2	0.2
	4	15.5	37.2	27.3	4.2	2.8	3.4	6.1	0.4
	5	37.1	7.5	17.4	1.3	10.8	0.6	5.1	0.1
	6	5.5	54.1	19.4	3.3	1.1	9.3	4.4	0.5
	7	6.2	52.6	21.1	2.3	1.5	8.7	4.3	0.6
	8	7.3	56.7	13.9	3.4	2.7	9.5	1.5	0.7
	9	208.0	57.4	26.3	15.9	7.5	1.1	1.5	0.5
	10	70.3	36.7	21.9	7.6	6.2	1.4	2.6	0.4
	11	69.5	110.3	69.1	17.5	3.1	3.9	2.9	0.6
	12	126.2	47.1	84.5	26.4	5.5	1.1	3.1	0.5
	13	212.1	811.5	419.4	132.7	1.8	7.6	4.1	1.0
	14	367.0	311.4	265.6	107.5	3.5	3.3	3.4	0.9
	15	160.5	656.4	453.5	230.8	1.0	3.9	3.9	1.0
	16	219.5	106.5	163.3	94.9	3.5	0.7	3.5	0.9

keys in Component 2 (VI 400 s and VI 1,800 s) remained constant throughout. The VI schedule on the left key of Component 1 varied across conditions (VI 150 s, VI 400 s, and VI 1,800 s).

Figure 3 shows the response rates to the two side keys in Components 1 and 2 as a function of the value of the varied VI schedule in Conditions 10, 14, and 15. Response rates on the right key during Component 1 showed the same pattern as those in Figure 2. As the arranged reinforcer rate on the left key decreased, the response rate on the right key increased. However, response rates on the left key were more unusual. When the left-key reinforcer schedule was changed from VI 150 s to VI 400 s, response rates to the left key increased. For Bird R4 in particular, the change in response

rates was quite large. This effect, attributable to the 24-hr closed-economy procedure, will be discussed later. When the left-key schedule was further increased to VI 1,800 s, left-key response rates showed the expected decrease.

Response rates during Component 2 showed clear evidence of multiple-schedule behavioral contrast. As the arranged reinforcer rate on the left key during Component 1 decreased, there were large systematic increases in the response rates on the left and right keys during Component 2 for both subjects.

Conditions 10, 14, and 16 provided the third set of conditions for examining behavioral contrast. The VI schedules on the left key of Component 1 (VI 400 s) and the left and right keys in Component 2 (VI 400 s and VI 1,800 s) remained constant throughout. The VI sched-

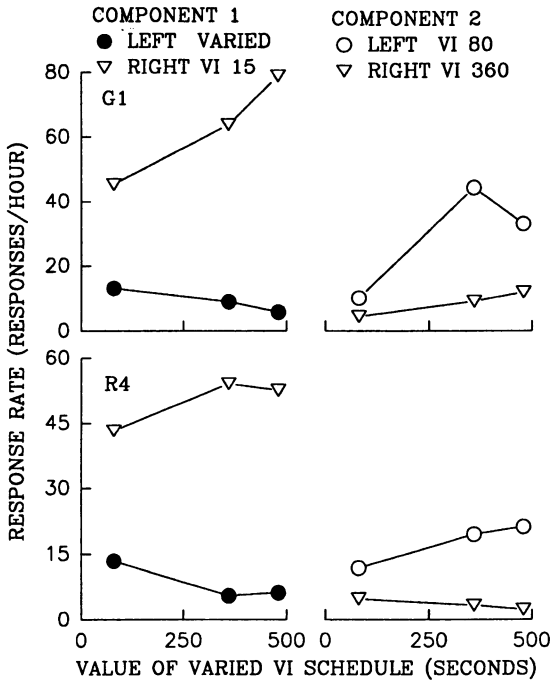


Fig. 2. The absolute response rates on each key for each component of the multiple concurrent schedule as a function of the arranged VI schedule on the varied key. The data are from Conditions 2, 6, and 7 for each bird.

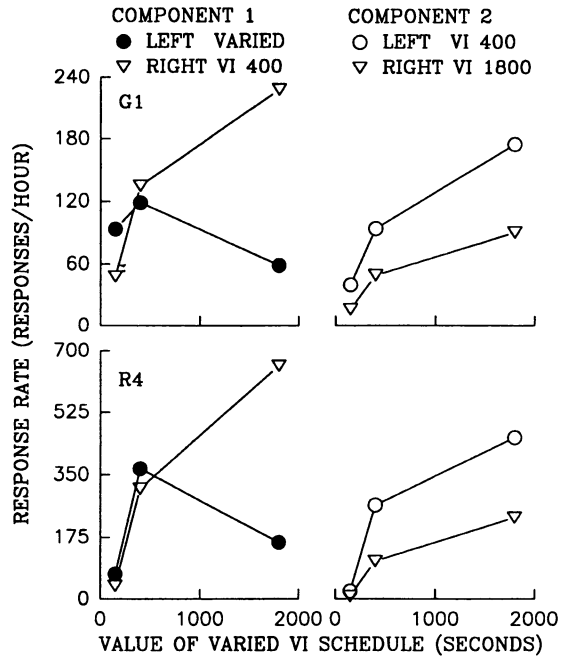


Fig. 3. The absolute response rates on each key for each component of the multiple concurrent schedule as a function of the arranged VI schedule on the varied key. The data are from Conditions 10, 14, and 15 for each bird.

ule on the right key of Component 1 varied across conditions (VI 150 s, VI 400 s, and VI 1,800 s).

The results from this third set of conditions (Figure 4, Table 2) were less clear than those previously presented in Figures 2 and 3, but the same general pattern was evident. In Component 1, response rates on the varied right key changed in the expected manner for Bird G1; that is, there were similar rates of responding for the VI 150-s and VI 400-s schedules and a substantial reduction for the VI 1,800-s schedule. Once again, Bird R4 showed a marked increase in response rate when the right-key schedule changed from VI 150 s to VI 400 s. When the right-key schedule was VI 1,800 s, however, there was the expected decrease in response rate (Figure 4). Response rates on the unchanged left key did not show the expected monotonic increases as the reinforcer rate on the right key decreased. Instead, left-key response rates decreased when the right-key schedule was changed from VI 400 s to VI 1,800 s. However, in both cases these latter response rates remained substantially

higher than those obtained when the right-key schedule was VI 150 s.

In Component 2, response rates to the left and right keys increased when the schedule on the right key of Component 1 changed from VI 150 s to VI 400 s (Figure 4). When the Component 1 schedule was changed from VI 400 s to VI 1,800 s, most Component 2 response rates did not change substantially. The exception was Bird R4's response rate on the left key, which did decrease but still remained higher than that obtained when the left-key Component 1 schedule was VI 150 s.

Figures 2, 3, and 4 collectively provide good evidence for behavioral contrast in multiple concurrent schedules. Response rates to the three constant VI schedules changed as the fourth VI schedule was varied. When the arranged reinforcer rate on the varied VI schedule decreased, response rates on the alternative concurrent schedule generally increased, as did response rates on both keys during the other component. In particular, there was an inverse relation between reinforcement rate in the varied component and response rate on the same

key in the constant component, as in standard multiple-schedule behavioral contrast.

Successive Independence

The generalized matching law (Equation 1) provided the basis for the analysis of successive independence between components of the multiple concurrent schedules. Two groups of conditions were analyzed in this manner. In each group the Component 1 concurrent VI VI schedules varied across a wide range of values, while the Component 2 concurrent VI VI schedules remained constant. Logarithms (Base 10) of the ratios of responses to the left and right keys were calculated for each component in each condition. Lines of best fit were calculated for the log response ratios in each component as a function of the obtained log reinforcer ratio in the varied Component 1.

Figure 5 shows the data from Conditions 1 to 7, in which the Component 2 schedules were always VI 80 (right key) and VI 360 (left key). For both birds, Component 1 responding was well described by the generalized matching law. Changes in the obtained reinforcer ratio produced systematic changes in behavior allocation, with slopes of 0.94 and 0.84 for Birds G1 and R4, respectively.

On the other hand, behavior allocation in Component 2 was independent of the response and reinforcer distributions in Component 1. Bird R4 showed this effect quite clearly; that is, the slope of the fitted line was very close to zero (0.05, Figure 5). Although the slope of the fitted line for Bird G1 was 0.36, this result was produced by the data from only one outlying condition. The data from the other six conditions are better described by a line with a slope of approximately zero (Figure 5).

Of the data presented in Figure 5, those from Conditions 2, 6, and 7 were also used in the analysis of behavioral contrast (Figure 2). These three conditions are shown by the filled symbols in Figure 5; their results were consistent with the overall pattern of results.

Figure 6 shows the results from Conditions 10 to 16 following the generalized matching law analysis. In these conditions, the Component 2 schedules were always VI 400 (right) and VI 1,800 (left). The results were consistent with those shown in Figure 5. The Component 1 data were well described by the generalized matching law, with positive slopes of 0.78 and 0.71. The data from Component 2

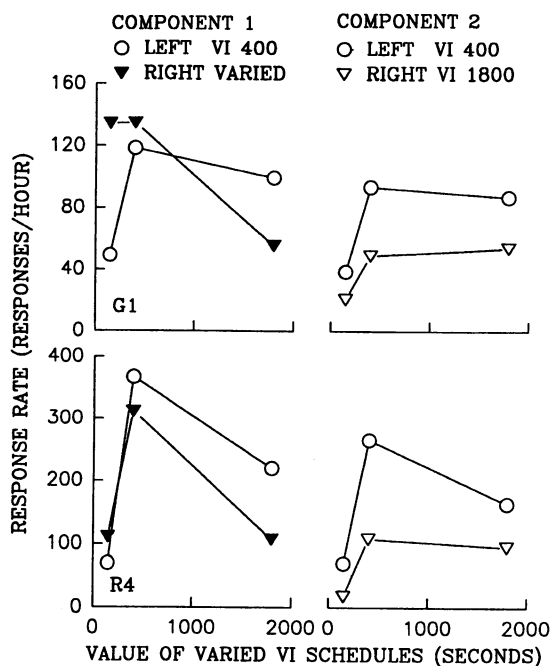


Fig. 4. The absolute response rates on each key for each component of the multiple concurrent schedule as a function of the arranged VI schedule on the varied key. The data are from Conditions 11, 14, and 16 for each bird.

showed no systematic variation as a function of the changes in reinforcement schedules in Component 1 (i.e., slopes of -0.03 and -0.02). Once again, the filled symbols represent the data from the conditions used in the analyses of behavioral contrast (Conditions 10, 11, 14, 15, and 16; Figures 3 and 4), and these data show no major deviations from the general pattern of results shown in Figure 6.

Figures 5 and 6 together provide good evidence for successive independence between components in 24-hr closed-economy multiple concurrent schedules. Behavior allocation during the constant Component 2 remained unchanged over a wide range of schedule changes in Component 1. Furthermore, those conditions that showed behavioral contrast in the earlier analyses (Figures 2, 3, and 4) also showed this successive independence.

DISCUSSION

The present experiment achieved its major aims. First, successive independence between components of multiple concurrent schedules

▼ & ▽ COMPONENT 1 (VARIED) ● & ○ COMPONENT 2 (VI 80 VI 360)

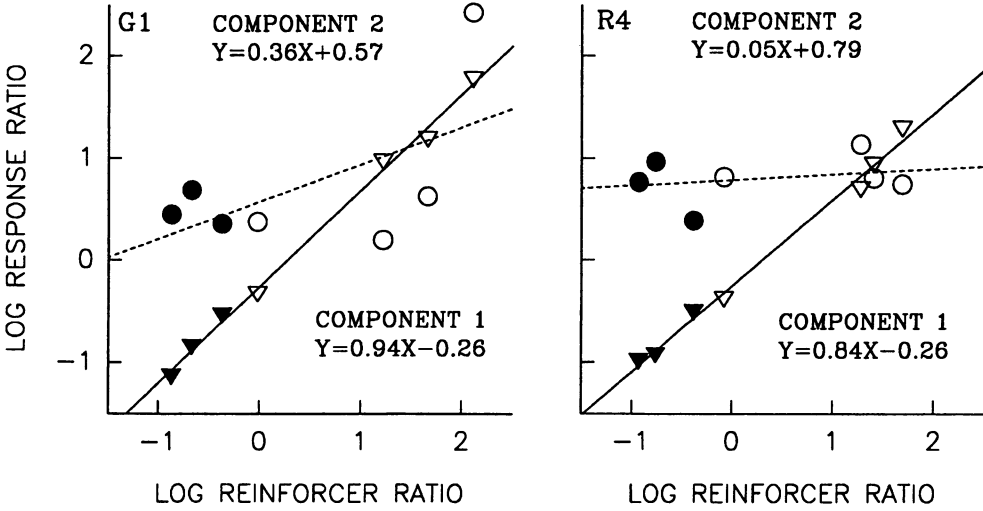


Fig. 5. Behavior allocation (left/right responses) across the concurrent schedules in each multiple-schedule component as a function of obtained reinforcers (left/right) in the varied Component 1. Equations for the fitted lines were obtained by least squares linear regression. The data are from Conditions 1 to 7 for each bird. The filled symbols mark data from conditions that appeared in the analysis of behavioral contrast.

occurs in 24-hr closed-economy procedures as well as in short (1 hr) open-economy sessions (e.g., McLean, 1988). Despite previous research showing major differences between various aspects of multiple-schedule performance

in closed and open economies (Elliffe & Davison, 1985; La Fiette & Fantino, 1988), successive independence is a robust result in both procedures. This generality is important because sessions that comprise most of an indi-

▼ & ▽ COMPONENT 1 (VARIED) ● & ○ COMPONENT 2 (VI 400 VI 1800)

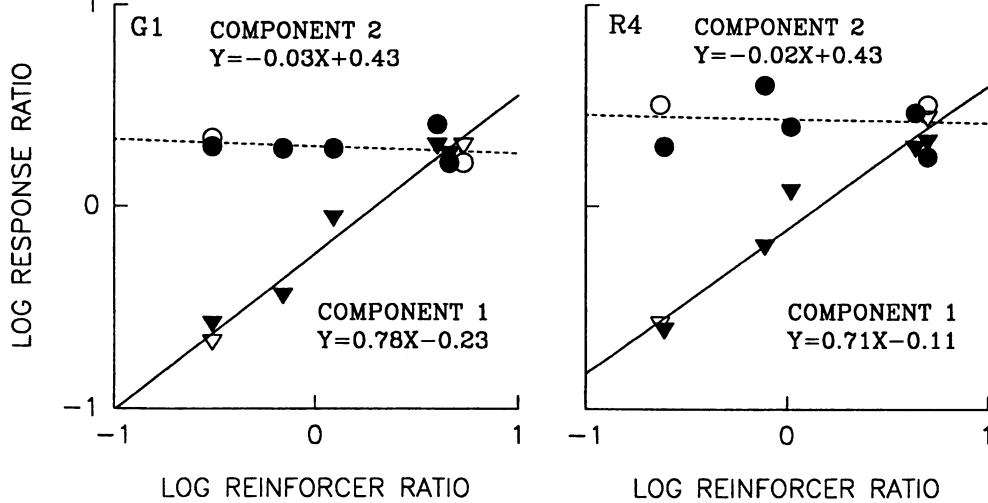


Fig. 6. Behavior allocation (left/right responses) across the concurrent schedules in each multiple-schedule component as a function of obtained reinforcers (left/right) in the varied Component 1. Equations for the fitted lines were obtained by least squares linear regression. The data are from Conditions 10 to 16 for each bird. The filled symbols mark data from conditions that appeared in the analysis of behavioral contrast.

vidual's day may reflect a more naturalistic situation than short sessions do (Baum, 1972, 1974a).

Second, the present study showed that behavioral contrast did not affect successive independence. In other words, although changes in one component influenced the total amount of key pecking in a second component, the manner in which key pecking was allocated in the second component remained unchanged. Furthermore, this result was obtained under conditions that produced large changes in overall response rates during the constant components (Figures 2, 3, and 4; Table 2).

Interpretation of the results of the present experiment might require some caution because only 2 subjects took part. On the other hand, the major findings seem consistent across the 2 subjects and across the various groups of conditions (e.g., Conditions 1 to 7 vs. Conditions 10 to 16). However, one aspect of the behavioral contrast results shown in Figures 3 and 4 needs to be specifically addressed. Bird R4 showed a large increase in response rate when the rate of reinforcement on the varied key was decreased (from VI 150 s to VI 400 s). This effect can be attributed to the nature of the closed economy. When the multiple concurrent schedules were VI 150 s VI 400 s (Component 1) and VI 400 s VI 1,800 s (Component 2), the overall arranged reinforcer rate was 22 reinforcers per hour. When the multiple concurrent schedules were VI 400 s VI 400 s (Component 1) and VI 400 s VI 1,800 s (Component 2), the overall arranged reinforcer rate was only 14.5 reinforcers per hour. This 34% decrease in overall reinforcer rate required responding for longer periods of each day in order to receive the same amount of food. Therefore, when the Component 1 schedules were changed from VI 150 s VI 400 s to VI 400 s VI 400 s, the increase in responding occurred on both schedules in that component.

The results of the present experiment provide support for McLean and White's (1983) interpretation of performance in multiple and multiple concurrent schedules. They argued that behavioral contrast in multiple schedules is not produced by the direct interaction between temporally removed components. Rather, they suggested that changes in overall response rates in unchanged components are mediated by changes in the availability of ex-

traneous reinforcers during that component (see also Staddon, 1982). Extraneous reinforcers are reinforcers other than those explicitly arranged by the experimental procedure. For example, extraneous reinforcers might include the consequences of preening or flapping.

This approach can be understood by considering each component of a multiple schedule as a concurrent schedule. One concurrent alternative is the schedule for arranged reinforcers, and the other concurrent alternative is the schedule for extraneous reinforcers (Herrnstein, 1970). Contrast reflects the differential allocation of behavior between arranged and extraneous reinforcers within each component (White, 1978). This approach leads to an equation for responding during one component of a multiple schedule that takes the form (McLean, 1991)

$$\log\left(\frac{B_1}{B_{e1}}\right) = (a - n) \log\left(\frac{R_1}{R_{e1}}\right) + n \log\left(\frac{R_2}{R_{e2}}\right) + \log c, \quad (2)$$

where B , R , a , and c are as defined in Equation 1. The subscripts 1 and 2 refer to the two multiple-schedule components, and the subscript e refers to extraneous reinforcers or behavior. The parameter n functions like the sensitivity parameter a ; however, in this case it measures the sensitivity of behavior allocation in Component 1 to the temporally removed reinforcer relations in Component 2.

Given that the reinforcer rate in Component 1 (R_1) remains constant, there are two obvious ways in which changing the reinforcer rate in Component 2 (R_2) can change Component 1 responding (B_1/B_{e1}). First, if n takes a value other than zero, then there is a direct effect of the Component 2 reinforcers on Component 1 responding (successive dependence). On the other hand, if n is zero (successive independence), then Component 1 responding can be affected by changes to the Component 2 reinforcer rate (R_2) only if that change leads to changes in the rate of extraneous reinforcers in Component 1 (R_{e1}).

However, Equation 2 eludes a direct test. The extraneous reinforcers (R_{e1} and R_{e2}) cannot be measured. An indirect test of Equation 2 can be conducted by scheduling a concurrent

alternative during each multiple-schedule component. Under these conditions, the effect that changing the reinforcer distribution in one component has on behavior allocation in the other component can be measured. This, of course, is a multiple concurrent schedule, as arranged in the present study. The successive independence between components found in the present study and in others (e.g., McLean, 1988) implies that n in Equation 2 is zero. Therefore, the change in response rates observed in simple multiple schedules (i.e., behavioral contrast) is produced by changes in the rates of extraneous reinforcers, that is, R_{e1} and R_{e2} in Equation 2 (see, however, McLean, 1991, for a different interpretation to account for local contrast). The generality of successive independence across a variety of procedures supports this interpretation.

Extraneous reinforcement also offers an explanation as to why the present experiment produced clear evidence of behavioral contrast but McLean's (1988, 1991) studies did not. McLean's multiple concurrent schedules ran for 1-hr sessions. During a session, most behavior involved responding to the concurrent schedules in order to obtain food. As a result, the overall rate of extraneous reinforcers might have been very low. For example, the birds might not preen at all during the session but would wait until they are returned to the home cage. Behavioral contrast could not occur if the rate of extraneous reinforcers was consistently at its minimum level. On the other hand, such constraints were very unlikely in the present experiment. A 24-hr procedure forces a continuous choice between food reinforcers and extraneous reinforcers (e.g., those associated with preening), and the range of extraneous reinforcers was much richer than in a standard experimental session (e.g., water and grit were also available). Therefore, the rate of extraneous reinforcers was unlikely to be at a minimum level, and this would allow the necessary changes to that rate in order to produce behavioral contrast.

In conclusion, Elliffe and Davison (1985) noted that no published approach to multiple-schedule performance, except that of McLean and White (1983), could immediately explain the extreme response differentials they observed in closed-economy 24-hr multiple schedules. Fittingly, the 24-hr procedure has

also provided clear support for one of the important foundations of the account for multiple-schedule performance in terms of concurrent interactions: the successive independence of behavior allocation between multiple-schedule components.

REFERENCES

- Alsop, B., & Elliffe, D. (1988). Concurrent-schedule performance: Effects of relative and overall reinforcer rate. *Journal of the Experimental Analysis of Behavior*, **49**, 21-36.
- Baum, W. M. (1972). Choice in a continuous procedure. *Psychonomic Science*, **28**, 263-265.
- Baum, W. M. (1974a). Choice in free-ranging wild pigeons. *Science*, **185**, 78-79.
- Baum, W. M. (1974b). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, **22**, 231-242.
- Catania, A. C. (1961). Behavioral contrast in a multiple and concurrent schedule of reinforcement. *Journal of the Experimental Analysis of Behavior*, **4**, 335-342.
- Elliffe, D., & Davison, M. (1985). Performance in continuously available multiple schedules. *Journal of the Experimental Analysis of Behavior*, **44**, 343-353.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, **5**, 529-530.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, **13**, 243-266.
- La Fiette, M. H., & Fantino, E. (1988). The effects of component duration on multiple-schedule performance in closed and open economies. *Journal of the Experimental Analysis of Behavior*, **50**, 457-468.
- Lander, D. G., & Irwin, R. J. (1968). Multiple schedules: Effects of the distribution of reinforcements between components on the distribution of responses between components. *Journal of the Experimental Analysis of Behavior*, **11**, 517-524.
- McLean, A. P. (1988). Successive independence of multiple-schedule component performances. *Journal of the Experimental Analysis of Behavior*, **49**, 117-141.
- McLean, A. P. (1991). Local contrast in behavior allocation during multiple-schedule components. *Journal of the Experimental Analysis of Behavior*, **56**, 81-96.
- McLean, A. P., & White, K. G. (1983). Temporal constraint on choice: Sensitivity and bias in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 405-426.
- Staddon, J. E. R. (1982). Behavioral competition, contrast and matching. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 243-261). Cambridge, MA: Ballinger.
- Taylor, R., & Davison, M. (1983). Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 191-198.
- Wearden, J. H., & Burgess, I. H. (1982). Matching since Baum (1979). *Journal of the Experimental Analysis of Behavior*, **38**, 339-348.

- White, K. G. (1978). Behavioral contrast as differential time allocation. *Journal of the Experimental Analysis of Behavior*, **29**, 151-160.
- Williams, B. A. (1983). Another look at contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 345-384.
- Williams, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzen, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology: Vol. 2. Learning and cognition* (pp. 167-244). New York: Wiley.

Received October 16, 1991
Final acceptance April 7, 1992